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Report

THE AIRBORNE SOUND INSULATIONS OF TIMBER-FRAMED PARTITIONS

G. D. Plumb, M.A. (Cantab.)

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Summary

The sound insulation performances of several lightweight, timber-framed partitions were measured in Research Department's Transmission Suite. The purpose was to assess the merits of various sheet materials and the effects of changes in the construction details on the sound insulation performances of the partitions. The aim was to produce a design for a new type of partition which was cheaper than the conventional 'Camden', which is currently widely used throughout the BBC.

As a result of the studies, a new design has been tested and will be recommended for use as a replacement for the Camden. It uses less material than the Camden, is much cheaper to build, and should be more tolerant of poor building practices.

Several recommendations are made on construction techniques, which apply whether the partition being built is a traditional Camden or the new design. Also, the use of fibreboard as a damping material for plasterboard is shown to improve the isolation of partitions greatly, much more than the consideration of its mass alone would lead one to expect.

Index terms: *Sound; sound insulation*

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1. Introduction 1
    - 1.1 The Camden 1
    - 1.2 Possible areas for improvements to the Camden 2
    - 1.3 Theory 2

2. Single Leaf Tests 3
    - 2.1 Single Camden 3
    - 2.2 Single skin tests 4
    - 2.3 Effects of fibreboard 4
    - 2.4 Effects of mineral wool 5
    - 2.5 Effects of extra sheets of plasterboard 5
    - 2.6 Effects of extra sheets of plasterboard and mineral wool 5
    - 2.7 Conclusions 6

3. Double Camden 6
    - 3.1 Introduction and method 6
    - 3.2 The effect of mastic around the edges of the plasterboard infill squares 6
    - 3.3 The complete double Camden 7
    - 3.4 Conclusions 7

4. Single Camden plus Paramount 8
    - 4.1 Introduction and method 8
    - 4.2 Observations 8
    - 4.3 Discussion 8
    - 4.4 Conclusions 9

5. Single Camden plus 19 mm plank 9
    - 5.1 Introduction and method 9
    - 5.2 Observations and discussion 9
    - 5.3 Conclusions 9

6. Single Camden plus two plasterboard layers on top of one fibreboard layer 9
    - 6.1 Introduction and method 9
    - 6.2 Observations and discussion 10
    - 6.3 Comparison with previous results 10
    - 6.4 Conclusions 10

7. Single Camden plus a sandwich of two plasterboard layers and one fibreboard layer 10
    - 7.1 Introduction and method 10
    - 7.2 Observations 11
    - 7.3 Discussion of potential problems with the new design 11
        - 7.3.1 Cavity leakage 11
        - 7.3.2 Impact isolation of the partition 12
    - 7.4 Conclusions 13
    - 7.5 Recommendations 14

8. Overall Conclusions 14

9. Overall Recommendations 14

10. References 15

Appendix: The Effect of Measurement Direction and Diffusion on the Calculated SRI of a Partition 16

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1. INTRODUCTION

1.1 The Camden

There is a common requirement within the BBC for lightweight partitions for separating studio areas. They are often needed because the maximum floor loading figures of the buildings, into which the studios are to be built, do not allow heavy brick or block walls to be used. A lightweight partition that is used in premises throughout the BBC is the 'Camden' — so named because it was developed for use in the Camden Theatre in the 1940s.

A cross-section through a triple Camden (i.e. having three separate, independently supported Camden leaves) is shown in Fig. 1. Double Camdens and single Camdens are also used extensively; practical aspects of the use of the Camden in studio environments are discussed in the Guide to Acoustic Practice[1]. The plasterboard provides the mass required for low frequency sound insulation, whilst the air trapped by the fibreboard and timber battens provides a good high frequency sound insulation. The fibreboard increases the sound insulation of the partition by four mechanisms:

a) It adds some mass to the partition.

b) It has a lower Q than the plasterboard and so it damps the motion of the plasterboard. In particular, it reduces the depth of the coincidence dip (see Section 1.3) which occurs at high frequencies if the plasterboard is used alone. As well as adding damping to the high frequency resonance of the plasterboard, the depth of the dip is also reduced by virtue of the fact that the fibreboard has a different coincidence frequency from that of the plasterboard. The fibreboard also adds a friction damping component as the surface of the fibreboard rubs against that of the plasterboard.

c) It acoustically treats the cavity in each leaf and so absorbs some of the sound that has leaked into it.

d) It acts as an anti-vibration mount (avm) between the plasterboard and timber battens and therefore reduces the mechanical coupling through the partition.

The Camden design has many merits which explains why it has not yet been superseded. It is lightweight for the level of sound insulation it provides; this allows savings in the cost of the building

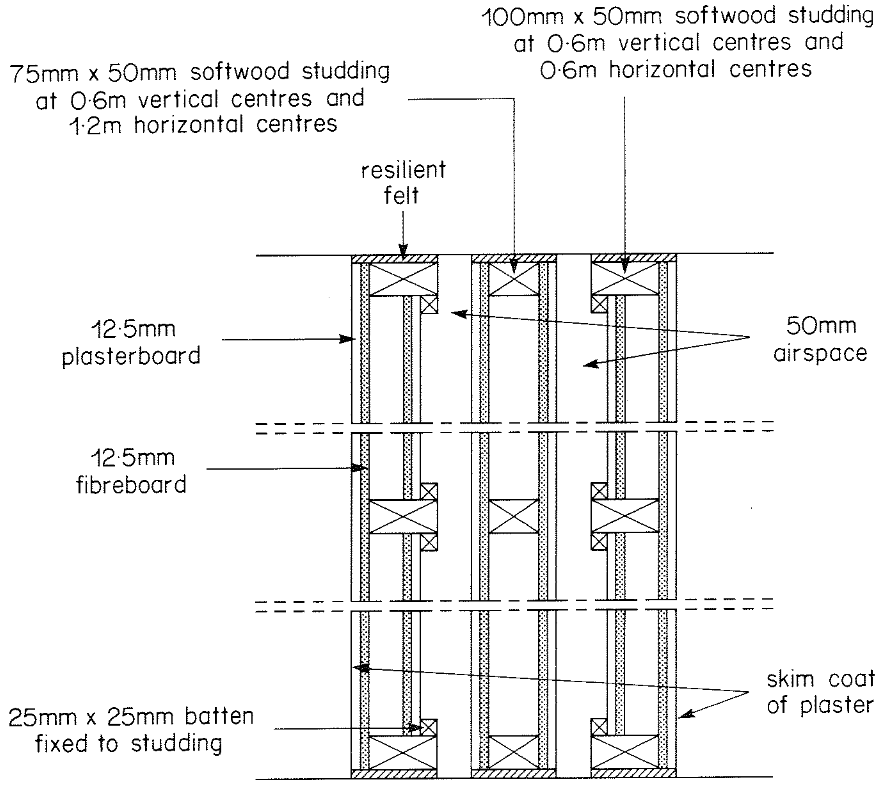

100mm x 50mm softwood studding at 0·6m vertical centres and 0·6m horizontal centres
75mm x 50mm softwood studding at 0·6m vertical centres and 1·2m horizontal centres
resilient felt
12·5mm plasterboard
50mm airspace
12·5mm fibreboard
skim coat of plaster
25mm x 25mm batten fixed to studding

Fig. 1 - Section through a triple Camden.

carcass into which studios are to be built. Studios with heavy masonry walls require strong, massive floors, and consequently the structure of the building carcass has to be considerably stronger. The Camden is also easier to remove than masonry walls, and less disruption is caused to other users of the building when studio areas are refurbished.

The Camden design does have some drawbacks. Although the mid and high frequency sound insulation it provides is good, its low frequency isolation is poor when compared with a masonry wall of similar width (the low frequency isolation is primarily determined by the mass of the partition). Camdens are also very costly in terms of the time required for construction. The infill squares of fibreboard and plasterboard, which are secured to the 25 mm × 25 mm battens, have to be individually cut to size, and any gaps have to be sealed with mastic. The design also allows much scope for errors and omissions in construction.

As detailed in Ref. 1, 12.5 mm thick plasterboard should always be used in preference to 9 mm plasterboard. Lightweight plasterboard should not be used. The joints at the board edges should always butt on the timber battens and the plasterboard edges should be offset from the fibreboard edges so that there is not a continuous sound leakage path to the timber at the edges of the boards.

The infill squares of fibreboard and plasterboard, which are secured to the 25 mm × 25 mm battens, should be individually cut and filed to size; any gaps should be sealed with mastic. The bottom row of these infill squares should be fitted last so that the cavity can be cleaned out just prior to fitting, to remove any potential acoustic bridges.

1.2 Possible areas for improvements to the Camden

Research Department's Transmission Suite[2] has been used to study the effects of small design changes on the sound insulation of partitions in a controlled laboratory environment. It was proposed that the Suite could be used to investigate ways in which the properties of the Camden might be improved. Changes may be desirable which result in:

a) An improved sound insulation, particularly at low frequencies.

b) A reduced cost and time required for construction.

c) A reduced partition width (to increase the studio floor area) or a reduced mass (to reduce the floor loading). These changes are not essential and are probably in conflict with the maintaining of a good sound insulation and so may be given a lower priority.

d) The elimination of 'wet-trades', i.e. plastering. Partitions using plasterboard will probably always be coated with a skim coat of plaster for cosmetic reasons. However, provided that the workmanship is good and that the boards are correctly fitted, there are no acoustic reasons why the skim coat is required and so it could already be eliminated.

There is the difficulty that the above changes conflict with each other. Therefore, it may have to be accepted that the sound insulation could be increased, while maintaining a similar construction cost or that the cost could be reduced, while maintaining a similar sound insulation, but that both improvements might not be possible together.

It was proposed that measurement of the sound insulations of various single and double leaf partitions, with designs related to that of the Camden, would give a valuable insight into the factors which control the sound insulations of lightweight partitions. With this insight and the above requirements in mind, design changes to the Camden could then be suggested and their effects could be measured and assessed. The results would also be applicable to triple leaf partitions, although triple leaf partitions were not tested because of constraints on time, cost and construction difficulties.

This work had two main aims. One was to quantify the behaviour of the different elements of the Camden partition and attempt to find cheaper alternative materials and construction details whilst retaining the acoustic performance. The second was to form a base for the development of potentially cheaper metal-framed alternatives[3].

1.3 Theory

The Sound Level Difference (SLD) measured between two rooms depends on a number of things: on the common partition area between the two rooms, on the reverberation time (RT) in the receive room and on the receive room volume. To make results for different partition materials and types of construction directly comparable, they are normalised to a Sound Reduction Index, SRI (or Transmission Loss, TL)[4], where

$$\mathrm{SRI} = \mathrm{SLD} + 10\log_{10}(ST/0.161V) \qquad (1)$$

where

S = area of test partition (m^2),
T = reverberation time in receive room (s),
V = receive room volume (m^3).

The mass law[5a] gives a simple relationship between the mass/area and the mean SRI of a partition. According to the mass law, doubling the mass per unit area gives an increase of 5 dB in the mean SRI of a partition. The effective calculated SRI of a partition will be reduced by flanking transmission of sound (i.e. sound that does not pass directly through the partition separating the source and receive rooms). Below a certain frequency which is controlled by the room dimensions, the calculated SRI will be inaccurate and will depend upon the measurement direction for reasons explained in the Appendix.

Although the industry standard practice for sound insulation specification and measurement covers the frequency range 100 Hz to 3.15 kHz, it is BBC practice to extend specifications and measurements down to a lower frequency; this is because of the more critical nature of that frequency range for broadcasting, especially for music. It is common BBC practice to evaluate SRIs in ⅓rd octave frequency bands, from band 17 (50 Hz) to band 40 (10 kHz). In addition, there are two useful single-figure measures of the sound insulation of a partition, R_{av} and R_w. They are useful for quick, approximate comparisons of the sound insulation performances of different partitions, although they should be used with care. One third octave plots of SRI give a more reliable comparison as they show up any weaknesses at particular frequencies.

R_{av} is the arithmetic average of the SRIs of a partition from 100 Hz to 2.5 kHz centred on 500 Hz. If the SRI at any frequency is unmeasurable because of background noise problems in the receive room, the symmetrical value about 500 Hz is excluded from the average. (In this way, the symmetry of the average with respect to 500 Hz is maintained.)

R_w is a value, to the nearest dB, obtained by fitting the SRIs of the partition, from 100 Hz to 3.15 kHz, to a reference curve with a constant shape but with a variable level. The level of the reference curve is altered until the adverse deviations of the SRIs of the partition below the reference curve fulfil certain conditions[6]. The level of the reference curve at 500 Hz is then equal to R_w.

High frequency dips in SRI curves can occur as a result of *wave coincidence*[5b]. Wave coincidence can occur when a sound wave strikes a panel at an oblique angle. At a certain frequency, the wavelength of the sound in the plane of the panel (which is inversely proportional to the sine of the incidence angle) will become equal to the natural bending wavelength of the panel and resonance will occur. At zero degrees incidence angle to the normal, this resonance frequency will be infinite. As the angle moves towards 90°, this frequency will lower to approach a *critical frequency*, which is the lowest frequency at which coincidence occurs.

In a reverberant field, the SRI of the panel will theoretically be given by the envelope of the minimum of all curves for all incidence angles. The bottom of the coincidence dip will occur at a frequency just above the critical frequency. The depth of the dip will be reduced by damping of the panel. For a single layer of 12.5 mm plasterboard, the critical frequency will be approximately 4 kHz, and for a single layer of 12.5 mm fibreboard it will be 8 kHz[5b]. If two identical layers of material are combined together to make a partition, resonance will occur at the same frequency as for a single layer, but the resonances in the two layers will reinforce and so the depth of the dip will be greater. Combining sheet materials with different critical frequencies to make a partition will tend to reduce the depth of the coincidence dip for each layer as the resonant frequencies for the different boards will not coincide.

2. SINGLE LEAF TESTS

To investigate the mechanisms of sound insulation in single leaf partitions, the sound insulations were measured for a number of partitions with designs related to that of the single Camden.

2.1 Single Camden

The sound insulation between the Transmission Suite source and receive rooms was measured with a single Camden built into the aperture between the two rooms. The purpose was to obtain a reference curve against which the performance of other single leaf partitions could be judged.

The results are shown in Fig. 2(a). General features of the sound insulation curve are:

a) A plateau from 50 Hz to 125 Hz, with a dip at 80 Hz. Possible causes of the dip might be either a panel resonance or a room mode — see the Appendix. The low frequency isolation of this type of lightweight partition is controlled by its mass.

b) A straight line extending from 125 Hz upwards with a slope determined by the number and type of boards used and the air space between the boards. The slope of the insulation curve for the single Camden is 9 dB/octave.

c) A shallow coincidence dip at 4 kHz which is caused by the plasterboard. However, there is no noticeable coincidence dip for the fibreboard at 8 kHz.

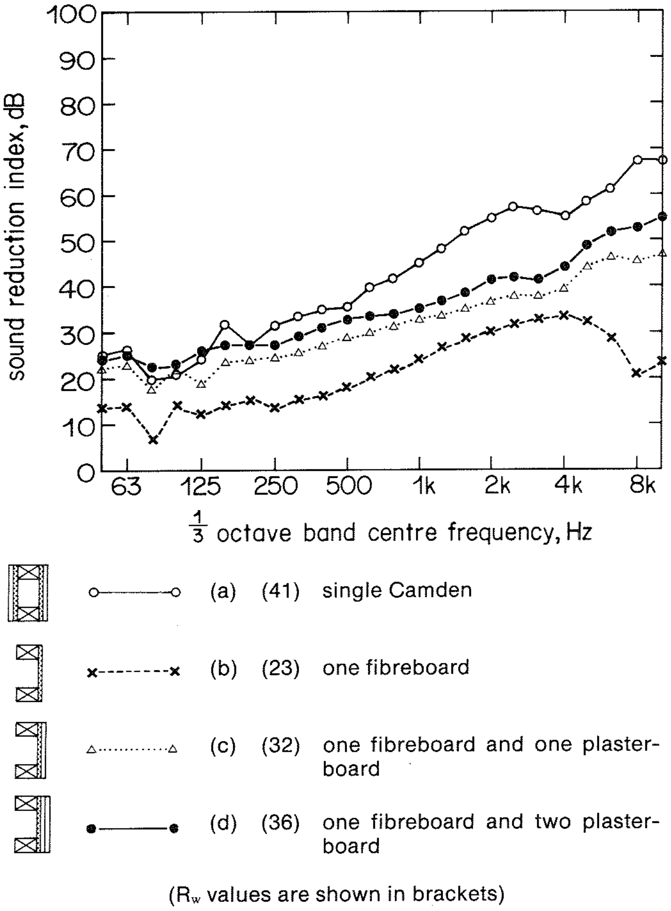


Fig. 2 - The sound insulations of various single leaf partitions.

2.2 Single skin tests

The sound insulations of three different single skin partitions were measured. The results are shown in Fig. 2 with the single Camden curve for reference. These measurements were useful because they gave an insight into the ways in which leaves interact in later double leaf tests.

(i) One layer of fibreboard — Fig. 2(b).

The sound insulation was measured of one layer of fibreboard on one side of 50 mm × 75 mm studding. The slope of the curve above 100 Hz is 6 dB/octave, which is the slope expected from the mass law[7]. There is a strong coincidence dip at 8 kHz which is the critical frequency for fibreboard.

(ii) One layer of fibreboard and one layer of plasterboard — Fig. 2(c).

Addition of the plasterboard to the fibreboard considerably increases the mass of the partition which explains the 8 dB increase in the sound insulation at low frequencies over the previous measurement. The slope of the curve above 100 Hz is 4 dB/octave, which is less than that for the single layer of fibreboard. There is one coincidence dip between 3.15 and 4 kHz (caused by the plasterboard), and another shallower coincidence dip at 8 kHz (caused by the fibreboard).

(iii) One layer of fibreboard and two layers of plasterboard — Fig. 2(d).

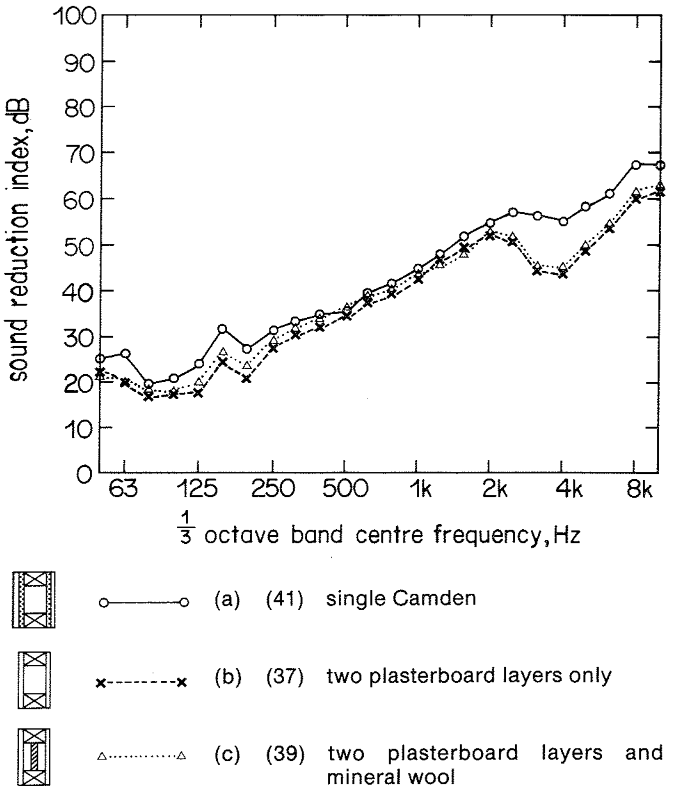
The sound insulation curve is very similar in shape to that where only one layer of plasterboard and one layer of fibreboard was fitted to one side of the 50 mm × 75 mm studding. However the sound insulation curve is approximately 4 dB higher when the extra layer of plasterboard was used, as would be expected from mass considerations alone.

The low frequency isolation for this skin is similar to that of the single Camden because their masses are similar. However the high frequency isolation is lower than that of the single Camden because the single Camden benefits from an air-cavity.

2.3 Effects of fibreboard

The sound insulations of a single Camden (Fig. 3(a)) and a single Camden without any fibreboard (Fig. 3(b)) (i.e. a conventional timber stud partition) were measured. The sound insulations were also measured with mineral wool in the cavity of the conventional timber stud partition (Fig. 3(c)) (i.e. without fibreboard), to show the relative merits of fibreboard against mineral wool for improving the sound insulations of the conventional timber stud partition. For the insulations of the partition without fibreboard, the effects of the mineral wool are slight; this can be explained in terms of the acoustic treatment that the mineral wool provides for the cavity.

The effects of the fibreboard on the sound insulation of the partition are much greater than the effects of the mineral wool. Using fibreboard, the isolation of the partition between 50 Hz and 250 Hz is 6 dB higher, on average, than the isolation of the partition using two layers of plasterboard only. This increase in the low frequency isolation is probably caused by the damping of the plasterboard. Using fibreboard, the average isolation between 315 Hz and 2 kHz is 2 dB greater than that of the partition using two layers of plasterboard alone. This increase in mid-frequency isolation can be accounted for solely because of the extra mass provided by the fibreboard. The partition without fibreboard has a much more pronounced coincidence dip between 2.5 kHz and



(R_w values are shown in brackets)

Fig. 3 - The effects of fibreboard or mineral wool on the sound insulation of a single leaf partition.

10 kHz than the single Camden. Fibreboard reduces the depth of the dip at the coincidence frequency of 3.15 kHz - 4 kHz by approximately 10 dB, by damping the resonance in the plasterboard and by virtue of the fact that the coincidence frequency of the fibreboard is higher than that of the plasterboard.

2.4 Effects of mineral wool

The sound insulation of a single Camden was measured with mineral wool in the cavity. The results are shown in Fig. 4. The mineral wool in the cavity increases the isolation by approximately 5 dB at all frequencies between 200 Hz and 6.3 kHz. Acoustically treating the cavity increases the sound insulation by absorbing some of the sound that has leaked through into the cavity.

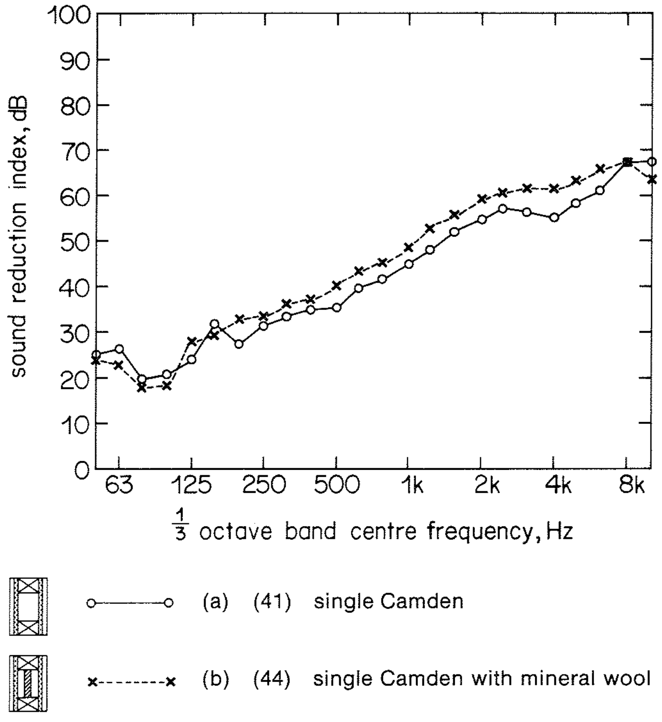
Note that the increase in isolation achieved by using mineral wool is greater than that for the conventional plasterboard on stud partition described in Section 2.3. This could be because of the vibration isolation afforded by the fibreboard in the single Camden. The airborne path for propagation of sound between the two skins of the single Camden appears to be dominant, so the acoustic treatment in the cavity is important. In the conventional plasterboard partition, the structure-borne path through the timber appears to be dominant, so the acoustic treatment in the cavity is less important.

2.5 Effects of extra sheets of plasterboard

The effects on the sound insulation of the single Camden of increasing its mass were investigated by screwing additional layers of plasterboard to the outer skins of the partition. The results are shown in Fig. 5. Adding two extra layers of plasterboard increases the isolation by approximately 4 dB in all bands, and this can be explained fully by the mass law.

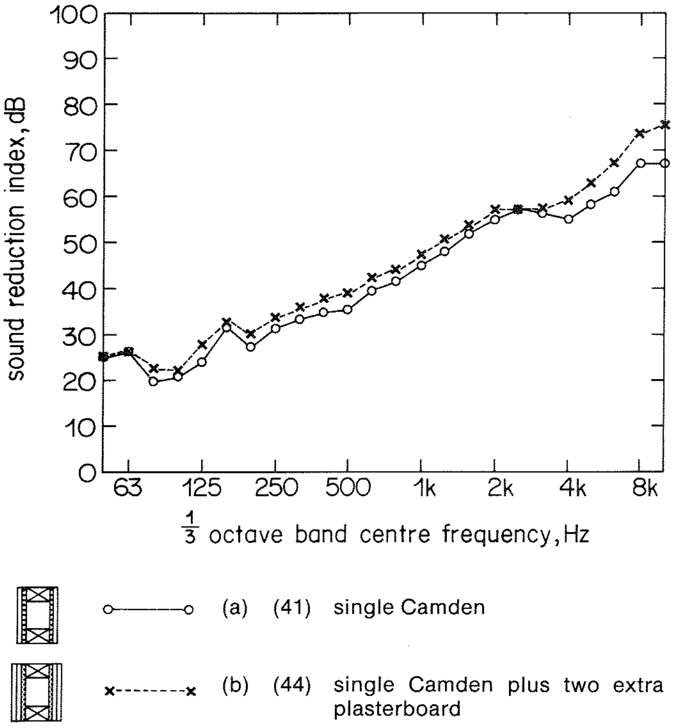
2.6 Effects of extra sheets of plasterboard and mineral wool

As a final experiment on single leaf partitions, the combined effects on the insulation, given by using extra sheets of plasterboard and mineral wool in the cavity of the single Camden, were investigated. The results are shown in Fig. 6. The mineral wool increases the isolation of the single Camden with two extra layers of plasterboard by approximately 1 dB in all frequency bands. This increase in the isolation is caused by the mineral wool absorbing sound that has leaked into the cavity. The increase in isolation obtained by using mineral wool in the single Camden alone has already been shown to be of the order of 5 dB in all frequency bands. Thus the effectiveness of



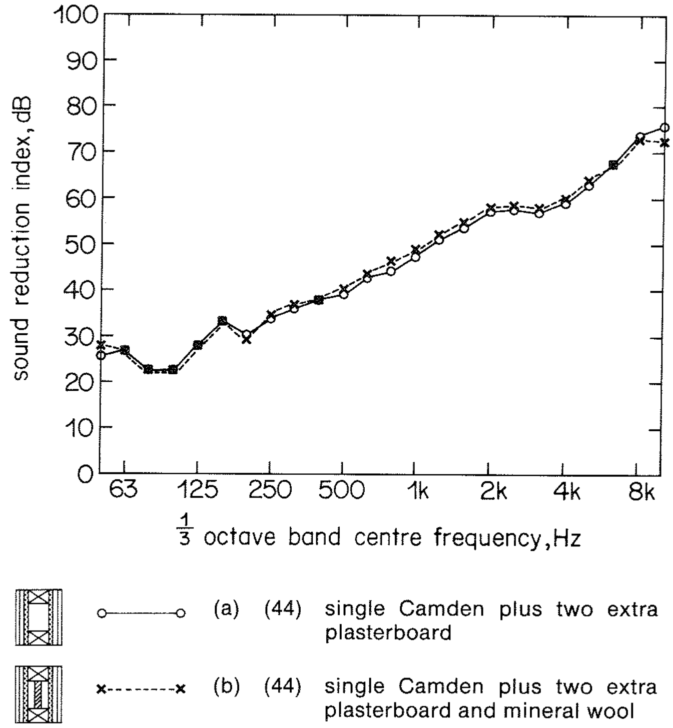
(R_w values are shown in brackets)

Fig. 4 - The effects of mineral wool on the sound insulation of a single Camden.



(R$_w$ values are shown in brackets)

Fig. 5 - The effects of extra sheets of plasterboard on the sound insulation of a single Camden.



(R$_w$ values are shown in brackets)

Fig. 6 - The effects of mineral wool on the sound insulation of a single Camden with extra sheets of plasterboard.

using mineral wool in the cavity of the single Camden reduces when extra plasterboard has been added. The reason for this is not obvious, although it might be that adding extra layers of plasterboard reduces the proportion of the sound that is transmitted through the cavity (airborne path) in relation to the amount that is transmitted via the studding (structure-borne path). The mineral wool would then have less effect as more layers of plasterboard are added for the reasons given in Section 2.4.

2.7 Conclusions

Several important conclusions can be drawn from these studies of the sound insulation performance of single leaf partitions:

a) Adding fibreboard to a conventional plasterboard-on-stud partition, to give a single Camden, increases the isolation from 50 Hz to 250 Hz by 6 dB because it damps the plasterboard. Between 315 Hz and 2 kHz, the fibreboard increases the isolation by 2 dB merely because of its mass. Between 2.5 kHz and 10 kHz the fibreboard greatly reduces the depth of the coincidence dip caused by the plasterboard. The overall increase in isolation caused by the use of fibreboard is large in relation to the extra mass involved.

b) Using mineral wool in the cavity of a single Camden increases the isolation of the partition at all frequencies by about 5 dB (by absorbing sound in the cavity).

c) Adding extra layers of plasterboard to the outer faces of the single Camden increases the isolation at all frequencies by an amount expected from the mass law.

3. DOUBLE CAMDEN

3.1 Introduction and method

The sound insulations between the source and receive rooms in the Transmission Suite were measured at each stage in the construction of the second leaf of a double Camden. The purposes were: to obtain a reference curve against which the performance of other double leaf partitions could be judged; to discover how sealing at board edges can affect the sound insulation; and to discover ways of simplifying the construction of the double Camden without compromising its sound insulation.

3.2 The effect of mastic around the edges of the plasterboard infill squares

To investigate whether narrow gaps at the edges of the boards of fibreboard or plasterboard could impair the sound insulations of partitions, the sound insulations at various stages in the construction of the double Camden were measured before and after filling the joints with either mastic or an all-purpose filler. The only case where filling the joints improved the isolation was for the plasterboard infill squares on the inner side of the second leaf of the double Camden. The isolation curves before and after filling are shown in Fig. 7. As expected for cracks, the improvement is greater at higher frequencies, and is as much as 6 dB.

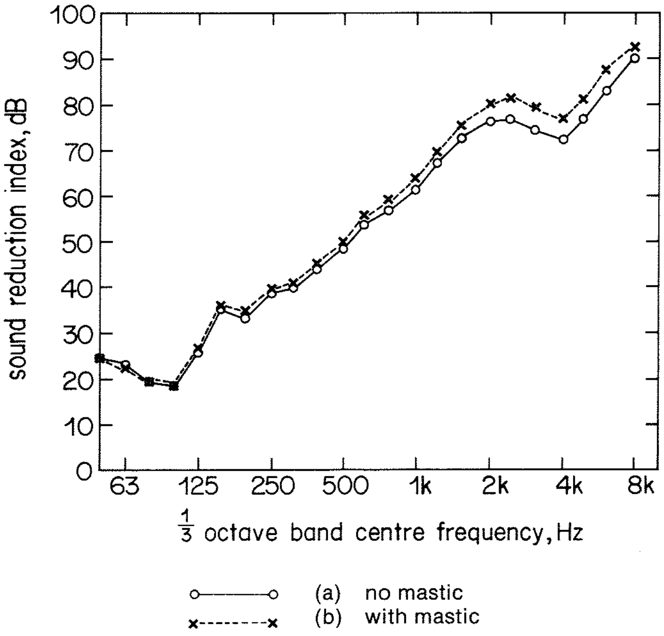


Fig. 7 - The effects on sound insulation of mastic around the infill squares.

Two conclusions on the use of the infill squares are:

a) If the Camden design is not altered, the plasterboard infill squares must always be sealed in place with mastic. Mastic was not necessary on the infill squares of fibreboard. Conversely, provided the standard of workmanship is good, a skim coat of plaster is not required to seal gaps at the edges of the boards.

b) The fitting of infill squares of plasterboard and fibreboard is undesirable as it is very time-consuming and costly. In addition, each square must be individually cut to size to ensure a good fit; even then, the plasterboard must be sealed at its edges with mastic.

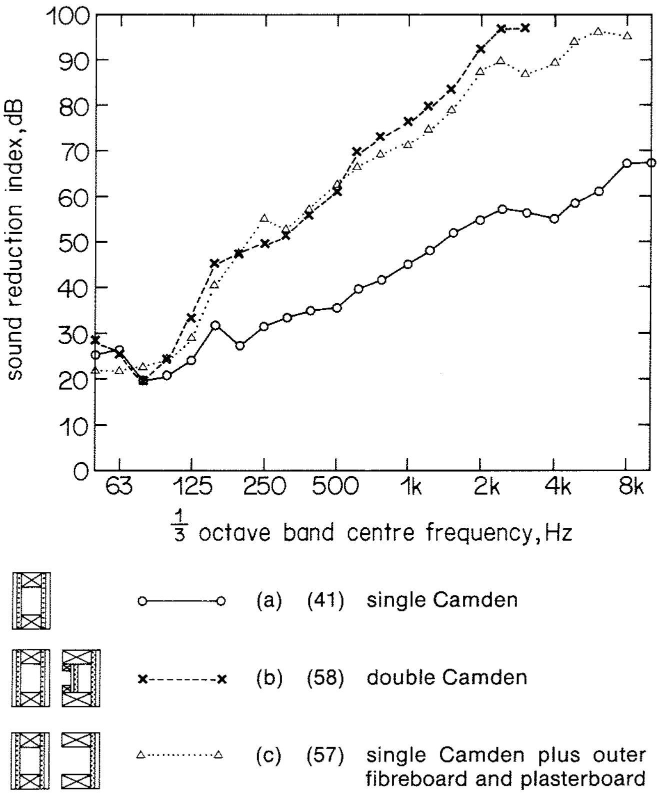
Poor workmanship, or insufficient supervision when the infill squares are being fitted, can lead to an appreciably impaired sound insulation performance. It is, therefore, desirable to modify the Camden design so that a construction method is used which is more tolerant of common building practices. The fitting of infill squares should be omitted and the sound insulation maintained by adding further sheet materials elsewhere.

3.3 The complete double Camden — Fig. 8(b)

The low frequency isolations are very similar to those of the single Camden (Fig. 8(a)). The double Camden would be expected to have low frequency isolations which were about 5 dB greater than those of the single Camden as a result of the mass law. Because this is not the case, it seems that panel resonances rather than the mass of the panels are controlling the low frequency isolations. The curve is somewhat uneven because of the effects of the various panel resonances caused by the high degree of symmetry in the partition construction.

3.4 Conclusions

When building a conventional double or triple Camden, each infill square which is fitted to the 25 mm × 25 mm battens must be cut to the exact size required. The joins at the edges of the plasterboard infill squares must be filled with mastic.



(R_w values are shown in brackets)

Fig. 8 - Stages in the construction of a double Camden.

4. SINGLE CAMDEN PLUS PARAMOUNT

4.1 Introduction and method

Fitting the infill plasterboard and fibreboard squares, to the inner-side battens of the second or third Camden leaves, is one of the most expensive and time-consuming aspects of double or triple Camden construction. It was worthwhile to investigate ways in which this aspect of the construction could be avoided. Omitting this infill layer of fibreboard and plasterboard would impair the overall isolation of the partition as shown in Fig. 8(c). However, the contribution to the overall sound insulation made by the infill squares is out of all proportion to their cost in construction time.

Because the layers of boards of the double Camden are all similar, and because the air-spaces are of similar width, panel resonances occur which make the sound insulation curves irregular. In modifying the design of the Camden, it would be useful to introduce a degree of asymmetry to reduce the likelihood of problems caused by dips in the isolation curves at certain frequencies.

It might be possible to omit the infill layer if the plasterboard and fibreboard on the outer of the second Camden leaf were replaced by a layer which contributed more to the overall sound insulation of the partition. It was suggested that a layer of British Gypsum Paramount dry partition would be suitable for this purpose. The Paramount partition used consisted of two 12.7 mm layers of plasterboard separated by, and bonded to, a 38 mm thick cardboard layer of cellular construction. Planed timber battens were used to support the edges of the sheet material, and screws were fitted through these to secure the boards to the outer face of the second timber stud leaf. Measurements were made with and without a layer of fibreboard between the Paramount and the second timber leaf.

4.2 Observations

The locations of the Paramount and other boards, and the results of the sound insulation measurements are shown in Fig. 9.

As well as damping the Paramount, the fibreboard also acoustically treats the cavity between the single Camden and the second leaf and so increases the isolation of the partition at all frequencies. These results again show proof of the usefulness of fibreboard.

The isolation curves are much smoother than that of the double Camden because of the asymmetry of the Paramount partition which discourages coincident resonances.

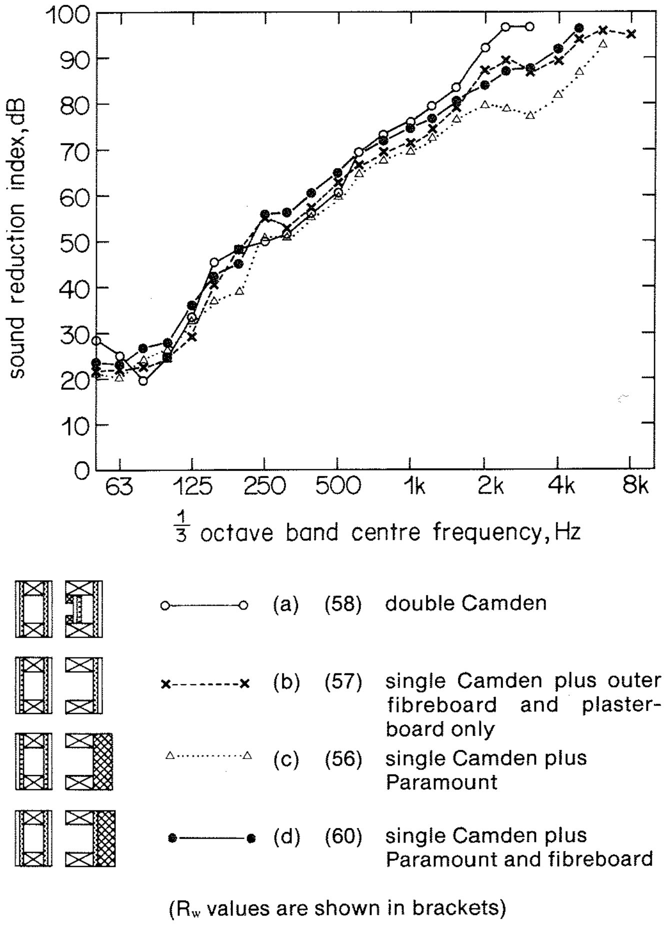


Fig. 9 - The sound insulations of Paramount partitions.

4.3 Discussion

The isolation for the partition, using Paramount and no fibreboard (Fig. 9(c)), is similar to, but slightly lower than for a single Camden plus a single layer of fibreboard and plasterboard on the outer of the second layer of studs (Fig. 9(b)). An explanation for this observation is that the average isolation of a partition of Paramount alone is 30 dB[8]; while the previous measurement for a single layer of plasterboard and fibreboard had an average isolation of 29 dB. The resultant isolation of the single Camden plus a leaf on the outer of the second stud can be shown, from earlier measurements, to be approximately equal to the isolation of the single Camden plus that of the second leaf (i.e. the two leaves behave independently). Thus, the isolations should be the same whether the Paramount or a single layer of fibreboard and plasterboard are used as the second leaf.

The fact that the single layer of plasterboard and fibreboard has a similar isolation to that of the Paramount is quite surprising because the Paramount layer is almost twice as heavy; also, it has the benefit of a 38 mm cavity. This observation suggests that the cardboard acoustically bridges the 38 mm cavity (the cellular cardboard is very rigid), and also highlights the beneficial effect of the fibreboard (the Paramount would be expected to have almost 4 dB more isolation than the single layer of plasterboard and fibreboard on considerations of mass alone).

When fibreboard was used to damp the Paramount (Fig. 9(d)), the resulting isolation was comparable with that of the double Camden, although the Paramount partition had a much smoother isolation curve.

4.4 Conclusions

The Paramount based partition using fibreboard had a comparable isolation with that of the double Camden, but it had two serious drawbacks:

a) Probably very little construction time would be saved over the double Camden because the Paramount is very heavy and difficult to fit. The installation of 37 mm planed timber battens is also very time-consuming. Therefore the cost saving would be small.

b) The partition is 50 mm thicker than a double Camden (if the design were extended to a triple leaf construction, it would be 100 mm thicker than a triple Camden).

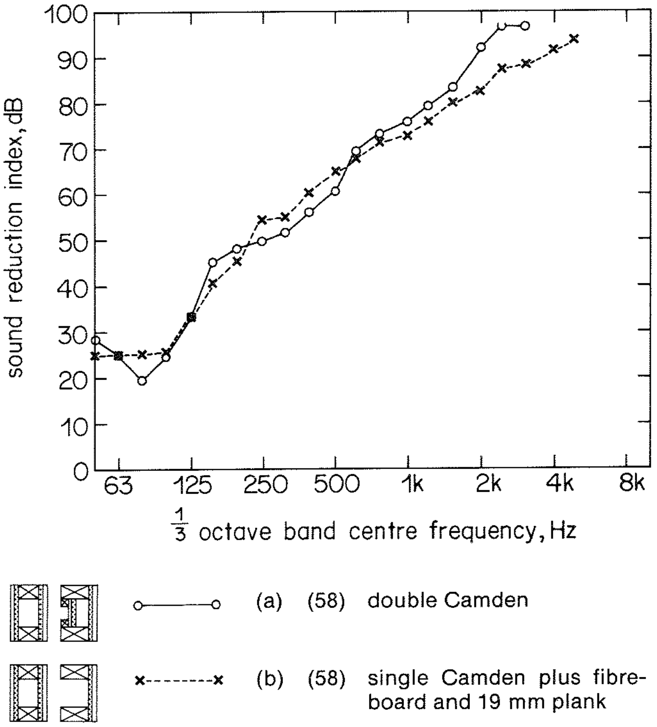
5. SINGLE CAMDEN PLUS 19 mm PLANK

5.1 Introduction and method

The partition based on Paramount described in the previous section did not show any great benefits over the double Camden. Therefore a different approach was adopted, and instead of the Paramount, 19 mm plasterboard planks were used. All previous measurements have suggested that the use of fibreboard is beneficial, and so only one measurement of the performance of the partition was made, and for this measurement fibreboard was used behind the 19 mm planks.

5.2 Observations and discussion

The locations of the boards, and the results of the sound insulation measurement are shown in Fig. 10. Once again, the curve is much smoother than that of the double Camden because the asymmetry of the partition discourages coincident resonances. The low frequency isolation is much better controlled than that of the double Camden. The overall isolation is comparable with that of the double Camden, although its isolation both in the range 160 Hz - 200 Hz and above 500 Hz is lower than that of the double Camden.



(R_w values are shown in brackets)

Fig. 10 - The sound insulation of a partition using 19 mm plank.

5.3 Conclusions

Apart from the isolations between 160 Hz and 200 Hz, the performance of the partition using 19 mm plank compares very favourably with that of the double Camden. Also the 19 mm plasterboard plank is more manageable and easier to fit than sheets of 12.5 mm plasterboard because of the smaller board dimensions (2.4 m × 0.6 m × 19 mm against 2.4 m × 1.2 m × 12.5 mm). However, it was felt that the design could be improved marginally and that the lower insulation of the second leaf at 160 Hz - 200 Hz might cause problems, especially if the design were extended to a triple leaf partition.

6. SINGLE CAMDEN PLUS TWO PLASTERBOARD LAYERS ON TOP OF ONE FIBREBOARD LAYER

6.1 Introduction and method

The partition based on 19 mm plasterboard plank, described in the previous section, was much easier and quicker (therefore less expensive) to construct than the double Camden, but its overall sound insulation performance was marginally less than that of the double Camden. Therefore a new experiment was carried out with two layers of 12.5 mm plasterboard in place of the 19 mm plasterboard plank.

6.2 Observations and discussion

The locations of the boards, and the results of the measurement are shown in Fig. 11. There is no low frequency dip unlike in the double Camden measurements which suggests that any panel resonance has been masked by using two dissimilar leaves.

6.3 Comparison with previous results

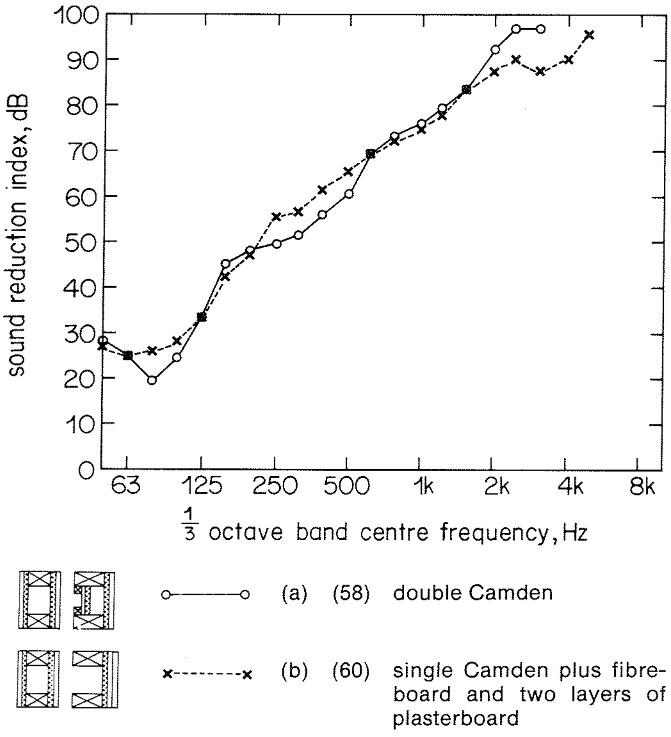
The isolations of this partition above 200 Hz are similar to those obtained by adding the isolations above 200 Hz of a single Camden to the isolations of the leaf described in Section 2.2 earlier, which shows that the two leaves are acting independently. The isolation curve of this partition is almost identical to that of the partition using Paramount damped with fibreboard. This shows that the cardboard and air-space in the Paramount had virtually no acoustic insulation effect. By comparing the results for the single Camden, plus a layer of fibreboard fitted to the outer of the second layer of studding, and coupled to either:

a) one layer of 12.5 mm plasterboard (Fig. 9(b)), or

b) one layer of 19 mm plasterboard plank (Fig. 10(b)), or

c) two layers of 12.5 mm plasterboard (Fig. 11(b),

it can be shown that the 19 mm plank is providing less isolation than would be expected from its mass. This could be because the area of each sheet of 19 mm plank is smaller than that of a 12.5 mm thick sheet of plasterboard which reduces their stiffness, as the boards are not perfectly restrained at their edges. Another possible reason for the isolation with 19 mm plank being lower than expected, is that the sheets have a smaller area than 12.5 mm plasterboard sheets, so the total crack area at the board edges will be higher.



(R$_w$ values are shown in brackets)

Fig. 11 - The sound insulation of a partition using a double layer of plasterboard.

6.4 Conclusions

The isolation curve of this new partition, using a double layer of plasterboard, is better than that of the double Camden except at very high frequencies. There is no low frequency panel resonance, and the isolation from 250 Hz to 500 Hz is approximately 5 dB better than that of the double Camden. The sound insulation curve is much smoother because of the asymmetry of the partition. The isolation curve of the partition is a much better fit to the general curves of sound insulation requirements between BBC studio areas than is that of the double Camden.

A discussion was held with the Bush House Clerk of Works*, after this partition had been tested, to discuss practical aspects of the design. There was some concern that the layer of fibreboard on the second leaf was exposed to the cavity between the two leaves and so the resistance of the partition to a fire in the cavity would be lower. On the conventional double Camden, fire resistance in the cavity is maintained by fitting the infill squares of plasterboard in the second leaf before fitting the infill squares of fibreboard. It is possible that, if the fire integrity of the double Camden was not important, the overall sound insulation could be increased if the fibreboard infill squares were fitted before the plasterboard infill squares. This is because the fibreboard would provide vibration isolation between the plasterboard and the timber frame.

7. SINGLE CAMDEN PLUS A SANDWICH OF TWO PLASTERBOARD LAYERS AND ONE FIBREBOARD LAYER

7.1 Introduction and method

To improve the fire resistance of the partition described in the previous section, the second leaf could be modified so that the fibreboard was sandwiched between the two layers of plasterboard. It might be thought that this would compromise the sound insulation performance of the partition. Referring to the purposes of the fibreboard listed in Section 1.1, it can be seen that the mass of the partition will be unchanged, the fibreboard will still damp the plasterboard by a similar amount, but the fibreboard will not act as an AVM for the second leaf. However, vibration isolation is not required between the plasterboard and the timber of the second leaf as, in this case, no boards are secured to the other side of the 50 mm by 100 mm studding; thus, there is very little surface area to transmit any vibration.

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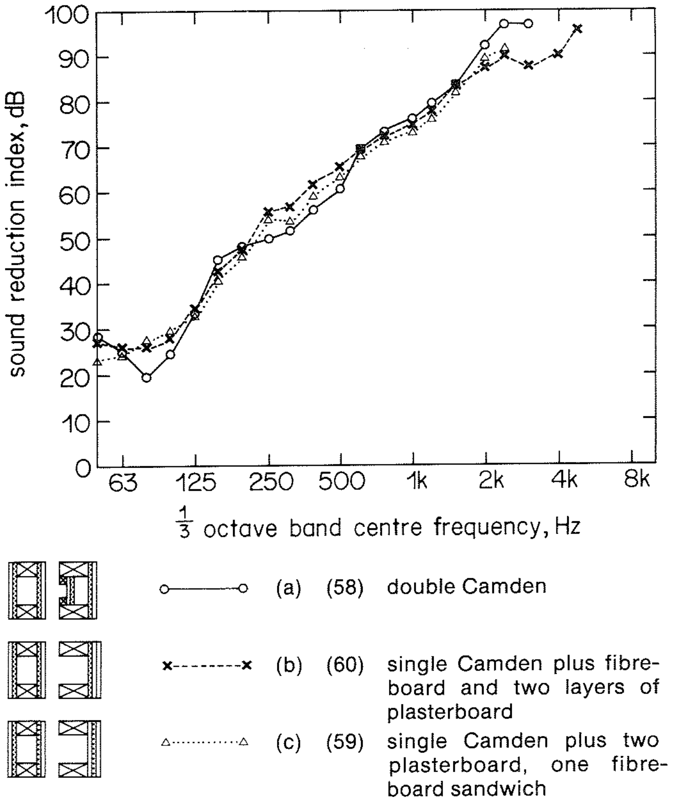
* George Helens

The only reason that the isolation for the sandwiched partition might be less than that described in Section 6 is that the cavity between the two leaves is not acoustically treated with fibreboard in the former case. To verify that the sound insulation performance of the partition was not significantly compromised, the sound insulation was measured after the order of the boards had been changed.

7.2 Observations

The location of the boards and the sound insulation curve are shown in Fig. 12(c). The isolations at low frequencies are generally higher than those of the double Camden because, although the mass was similar, panel resonances would have been discouraged by the lack of symmetry of the partition.



(R_w values are shown in brackets)

Fig. 12 - The sound insulation of new partition.

Converting the second leaf into a fibreboard sandwich, slightly reduced the airborne sound insulation of the partition over the 315 Hz to 500 Hz range. As anticipated above, this happened because the fibreboard was no longer acoustically treating the cavity between the two leaves. However, the overall sound insulation performance of the new sandwich partition was still better than that of the double Camden.

7.3 Discussion of potential problems with the new design

7.3.1 Cavity leakage

It was suggested that the new type of partition might suffer more than the double Camden from problems caused by leakage of sound into the cavity between the two leaves. For example, if sound could bypass the first leaf (e.g. because of a fault in a door or window detail), then the sound insulation would be further compromised if the sound insulation provided by the newly designed second leaf was less than that of the corresponding leaf of the double Camden.

To discover whether this hypothesis was true, a loudspeaker was fitted into the cavity between the two leaves of the partition together with a calibrated microphone on a stand. The isolations were then measured between the cavity and the source room (new leaf dividing), and between the cavity and the receive room (single Camden dividing). The isolations were corrected for the receiving room reverberation times, and the results are shown in Fig. 13. Note that this is only an approximate test of the resistance of the partition to problems caused by ingress of sound into the cavity, as the sound field in the cavity will not be well defined.

The difference between the two isolation curves increases from a small value at low frequencies up to approximately 10 dB at high frequencies. The isolations can be compared directly with those shown in Fig. 2 for each leaf measured independently (note that the fibreboard was not sandwiched between the two layers of plasterboard in the test of Fig. 2(d), although this difference probably would not have greatly affected the results). The isolation curves for the cavity measurement and the independent leaf measurement, have different shapes and levels (because the leaves in the double partition are not independent and because the field in the cavity is not well defined). However, the difference between the isolation for the single Camden leaf and the isolation of the new leaf, is very similar for the independent measurement and the cavity measurement. This suggests that the effectiveness of a partition, in preventing sound that has leaked into its cavity from reaching a room on one side of it, can be estimated by knowing the

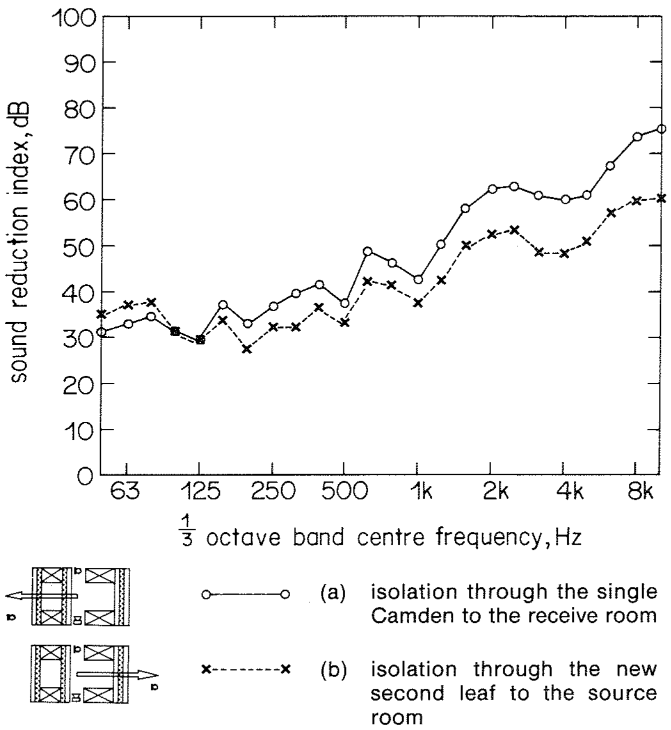


Fig. 13 - Isolations from the cavity of the new partition to outside.

airborne sound insulation of the leaf between the cavity and the room as measured independently elsewhere.

The isolations from the cavity of a traditional double Camden to either the source room or the receive room had not been measured. Also, the isolation of the second leaf alone of the double Camden (the leaf with the infill squares) had not been measured. However, an approximate value for its isolation, when it is independently mounted, can be estimated, given that the isolation will be lower than that of the conventional single Camden, for four reasons:

a) The cavity in the second leaf of a double Camden is only 50 mm wide as opposed to being 75 mm wide in the single Camden. By referring to manufacturers' literature on similar types of partition[8], it can be estimated that because of the smaller cavity width, the second leaf will have a low frequency isolation very similar to that of the single Camden, but its isolation will gradually fall short of that of the single Camden to the extent of an approximately 4 dB lower value at 10 kHz.

b) The fibreboard associated with the infill squares of plasterboard is not acting as an AVM between the plasterboard and the timber studding.

c) There is a greater chance of sound leakage at the weakness of the 25 mm × 25 mm battens than at a normal joint on the face of the timber stud.

d) As explained in Section 6.3, using smaller board sizes probably reduces the stiffness and isolation of the partition. The infill squares are much smaller than full sized boards and so would compromise the isolation.

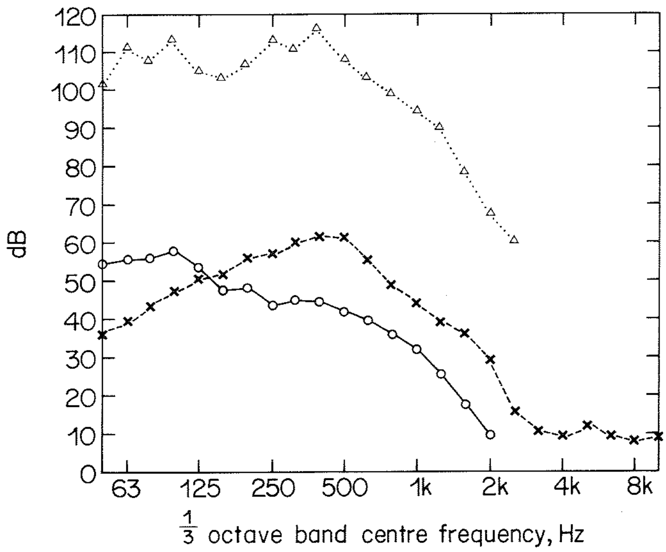
It is not possible to give accurate values for the reduction in isolation caused by the last three factors, although a reasonable estimate might be that the combined effect of all three factors would have a similar magnitude to that of factor (a).

Thus, the resistance of the new second leaf to sound that has leaked into the cavity would be similar to that of the second leaf of a traditional double Camden at low frequencies; the resistance of the new leaf would gradually fall below that of the traditional second leaf until it was a few dB down at high frequencies. The potential loss in isolation from the cavity can, however, be offset against the simplification of the design of the second leaf, which should make partitions more reproducible and less prone to impaired isolation curves as a result of poor construction technique.

7.3.2 Impact isolation of the partition

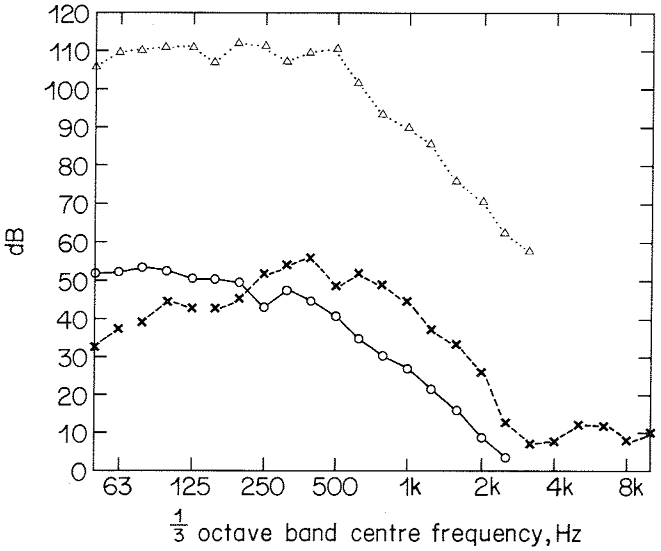
The new partition might also have a lower impact isolation than that of the traditional double Camden. Although the impact isolation of the traditional double Camden had not been measured, some useful information could be obtained by measuring the response of the partition to impacts on either side of the partition. An electronic finger (i.e. an electromagnetic device which produces repetitive impacts like a finger tapping on a surface) was used to hit the partition at three separate positions on each side of the partition. At each position, the finger was supported at a fixed distance from the partition, so the peak impulsive force would therefore have been constant. One accelerometer was secured to a metal disc, which was glued to the source room side of the partition, and another accelerometer was secured in the same way to the receive room side of the partition (to measure horizontal motion). Also, the s.p.l. in the source room was measured when the finger impacts were on the receive room side of the partition; the s.p.l. in the receive room was measured when the finger impacts were on the source room side of the partition.

The averaged results of the measurements are shown in Fig. 14 and Fig. 15. The accelerations and



o——o (a) corrected s.p.l. in the receive room
×--------× (b) acceleration of the source room side of the partition
△··········△ (c) acceleration of the receive room side of the partition

Fig. 14 - Impact tests on the source room side of the partition.



o——o (a) corrected s.p.l. in the source room
×--------× (b) acceleration of the receive room side of the partition
△··········△ (c) acceleration of the source room side of the partition

Fig. 15 - Impact tests on the receive room side of the partition.

s.p.l.s are referenced to arbitrary levels, and the s.p.l.s have been corrected as appropriate for the reverberation time in each case. For both measurement directions, the vibration on the side of the partition being hit is much greater than the vibration on the other side of the partition which shows that there was very little mechanical coupling between the two leaves of the partition. For both measurement directions, the corrected s.p.l.s in the receiving rooms are similar, as are the accelerations on the side of the partition not being hit. This is expected from the theory of reciprocity. The accelerations of the side of the partition suffering the impacts are also very similar for both measurement directions. This implies that the impedance of the new second leaf of the partition is very similar to that of a single Camden (the first leaf); so the overall impact isolation of the new partition should not differ greatly from that of a traditional double Camden.

7.4 Conclusions

The isolation curve of this partition is better than that of the double Camden. There are fewer low frequency panel resonances, and the isolation from 250 Hz to 500 Hz is approximately 3 dB better than that of the double Camden. The sound insulation curve of the new partition is much smoother than that of the conventional double Camden because of the asymmetry of the new partition. The isolation curve of the new partition is also a better fit to the general curves of sound insulation requirements between BBC studio areas than that for the double Camden. The impact isolation of the new partition should be similar to that of the traditional Camden.

More importantly, the partition actually uses less material (one less layer of fibreboard and no 25 mm × 25 mm timber battens) than the double Camden and the associated savings in labour costs are large. The partition weighs marginally less than the double Camden. In addition, the partition should be more tolerant of poor workmanship and building supervision than the double Camden as the infill squares on the conventional double Camden are very difficult to install correctly.

It might be thought that the size of the second stud could be reduced from 50 mm × 100 mm to 50 mm × 75 mm to save on partition width and materials. However it is recommended that this is not done for two reasons:

a) Reduction of the air-space between the two leaves would probably reduce the sound insulation of the partition and any associated multi-pane windows or multiple doors.

b) More importantly, the strength of the 50 mm × 100 mm timber may be required for the structural support of the usual heavy wood-wool slab ceiling and the air-conditioning systems together with support of the acoustic treatment.

Making the second leaf into a fibreboard sandwich slightly reduced the airborne sound insulation of the partition. This happened because the fibreboard was no longer acoustically treating the cavity between the two leaves. However the fire integrity of the cavity is retained by *not* exposing the fibreboard to the air in the cavity.

The partition design could be extended to provide a triple leaf partition as a replacement for the triple Camden by repeating the sandwiched leaf on the other side of the single Camden in the new double leaf partition. It is expected that this triple leaf partition would have a similar sound insulation performance to that of the triple Camden because the new double leaf partition had a similar performance to that of the double Camden. Following a similar argument to that for the new double leaf partition, the new triple leaf partition would have a similar mass to that of the conventional triple Camden, and its degree of asymmetry should give a higher low frequency sound insulation to the new partition. The leaves would probably behave independently above 200 Hz, as for the double leaf partition, and the sound insulations of each leaf of the triple partition measured independently could be added to give an estimate of the overall sound insulation performance of the triple partitions. This suggests that the new triple partition would have a similar sound insulation performance to that of the conventional triple partition.

7.5 Recommendations

This new type of partition should be built in a real studio environment to see if there are any practical problems that arise from its use (such as leakage into the cavity — although it is not envisaged that this will cause problems). A good comparison of its performance with that of the traditional Camden could be obtained by building two identical studio areas, one using traditional Camdens, and the other using the new type of partition. Comparison of the corresponding isolations in both areas would then show up any weaknesses in the new partition design compared to that of the traditional Camden. Also, triple leaf versions of the partition design could be tested to ensure that a similar performance to that of the conventional triple Camden is achieved.

8. OVERALL CONCLUSIONS

Several novel partitions have been investigated, with the aim of designing a cheaper alternative to the Camden. Paramount partitioning is unsuitable for use in studios because of its poor sound insulation performance in relation to its size and mass. It is also costly and time-consuming to assemble. 19 mm plasterboard plank is manageable and easy to use, although the partition tested, which used 19 mm plank, just failed to have a sufficient sound insulation to make it comparable with the double Camden.

A new partition design has been tested and will be recommended as a replacement for the double Camden where traditional wooden frame construction is desired. This replacement omits the costly 'infill' sections of fibreboard and plasterboard and uses a sandwich of two layers of 12.5 mm plasterboard and one layer of 12.5 mm fibreboard. It requires slightly less material than the double Camden and should be much cheaper to build and more tolerant of poor building practices. It also has a slightly higher sound isolation than that of the double Camden; its sound insulation curve is much smoother and does not suffer from dips at low frequencies. It is envisaged that the design could be extended to give a triple leaf partition with a comparable sound insulation performance to that of the conventional triple Camden.

Fibreboard has been shown to provide large increases in sound insulation for its mass because of its ability to damp the motion of plasterboard. It also significantly reduces the depth of the coincidence dip for plasterboard because of its higher critical frequency and by adding damping.

Mineral wool in the cavity of single leaf partitions appreciably increases their sound insulations. The increases in isolation probably would be less if mineral wool was used in the cavity of double or triple leaf partitions, a point which was verified in later studies on the sound insulation of lightweight metal-framed partitions[3].

Adding extra layers of plasterboard to a single leaf partition merely gives an increase in sound insulation that can be predicted from the mass law.

Most of the findings of this Report are directly applicable to the design of metal-framed partitions[3]. The latter have been shown to give even greater cost savings whilst maintaining a comparable sound insulation.

9. OVERALL RECOMMENDATIONS

a) Paramount partitioning should not be used in studios because of its poor sound insulation for its size and mass, and because of the high cost of installation.

b) 19 mm thick plasterboard plank should not be used for partitions because the plank gives a poorer isolation for its mass than boards with a larger surface area.

c) Field trials of the sound insulation performance of the newly proposed timber-framed partition design should be carried out in a studio environment to discover whether there are any unforeseen weaknesses before it is recommended for widespread use. The sound insulation performance of a triple leaf version of the partition should be compared against that of a conventional triple Camden.

d) 12.5 mm plasterboard should be used in preference to 9 mm plasterboard. The joints at board edges must always butt on the timber battens and the boards should be offset so that subsequent layers have their joints on different studs.

e) When building a traditional double or triple Camden, the infill squares of plasterboard and fibreboard should be individually cut and filed to size. The plasterboard infill squares must be sealed in place with mastic. The bottom row of infill boards should be fitted last so that the cavity can be vacuumed out to remove any acoustic bridges.

f) Mineral wool should be used in the cavity of single leaf partitions where the sound insulation requirements dictate that it should be, provided that the increased cost is justifiable.

10. REFERENCES

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APPENDIX

The Effect of Measurement Direction and Diffusion on the Calculated SRI of a Partition

As mentioned in Section 1.3, the calculated SRIs of a partition should not depend on the measurement direction (i.e. which of the two rooms separated by the partition is used as the source room), even in the presence of flanking transmission of sound. However, in some recent measurements in new studio areas at Television Centre, the SLDs at low frequencies, measured in opposite directions, differed more than could be explained by the appropriate receive room volumes and reverberation times.

To study this effect further, the SLDs were measured, in both directions, between the source and receive rooms of the Transmission Suite (for a partition not described in this Report). The reverberation times in the source and receive rooms were also measured. The SRIs of the partition were calculated for both measurement directions by substituting into equation (1) the relevant SLDs, the receiving room volume and its reverberation times, and the partition area. The results are plotted in Fig. A1. Above 80 Hz, the two curves show extremely close agreement. However, between 50 Hz and 80 Hz the agreement is relatively poor and the two curves differ in value by as much as 6 dB.

The theory used to calculate the SRIs of a partition does not apply at low frequencies, where the modal density in the source and receive rooms is small (i.e. where the wavelength of the sound is large compared with the dimensions of the rooms). Even if the response of the loudspeaker in the source room is relatively flat in frequency response, the partition will be excited predominantly at the modal frequencies of the source room, and the partition will generally produce a higher receive room s.p.l. at the modal frequencies of the receive room. If a panel resonance frequency is the same as a modal frequency of the source or receive room, the measured isolation will be particularly poor. The ⅓rd octave measurements become dominated by the s.p.l.s at particular resonant frequencies.

The variation with the measurement direction of the calculated SRIs at low frequencies probably occurs as a result of several factors. The spatial average of the s.p.l. in a room, measured using several fixed microphone positions or using a microphone on a rotating boom, will not be a good estimate of the average s.p.l. in the room at low frequencies (where the variation of s.p.l. with position in the room will be large). Also, the SRIs will be dominated by the s.p.l.s at the resonant frequencies of the rooms or partition. The loudspeaker in the source room approximates to a spherical point source, whereas the partition acts as a plane distributed source to the receive room; so the measurement direction may influence the extent to which modes are set up in either room. In theory, the principle of reciprocity implies that the SRI measured at a fixed frequency should be independent of measurement direction, but the above reasons may explain why the ⅓rd octave results depend on measurement direction at low frequencies.

The degree of variation with measurement direction of the SRIs of the partition in the Transmission Suite, is sufficient to explain the variation with measurement direction of the SLDs at Television Centre. For measurements in the Transmission Suite, the differences between the two curves (for opposite measurement directions) at low frequencies are random in magnitude and sign. This was not the case for the measurements at Television Centre. This may be because the room modal frequencies, between the Transmission Suite and the new studios at Television Centre, differ, as do the partition resonant frequencies.

These observations highlight the problems with interpreting isolations measured at low frequencies. However, provided sufficient microphone positions are used, the SLDs measured in studios at low frequencies are meaningful and they indicate whether there are likely to be problems with ‘howl-round’. It is very important to note, that care should be taken in selecting the room shapes and volumes when designing studios, and that these parameters are as important as Transmission Suite measurements of the low frequency isolation of the partitions used. In general, larger studios, with a higher modal density at low frequencies, will suffer less from problems of unpredictability of their low frequency isolation to or from other areas. Another very important related point to note, is that measurements made in Research Department’s Transmission Suite below 100 Hz will not be reproducible in other Transmission Suites. However, provided the same loudspeaker positions and microphone swept paths are used, the results may show up differences caused by partition design changes, even if the absolute SRIs are inaccurate or unreliable. Acoustic treatment is currently being used in both the source and receive rooms of the Transmission Suite when measuring the sound insulation of test partitions; one purpose of this is to try to reduce the effects of room modes.

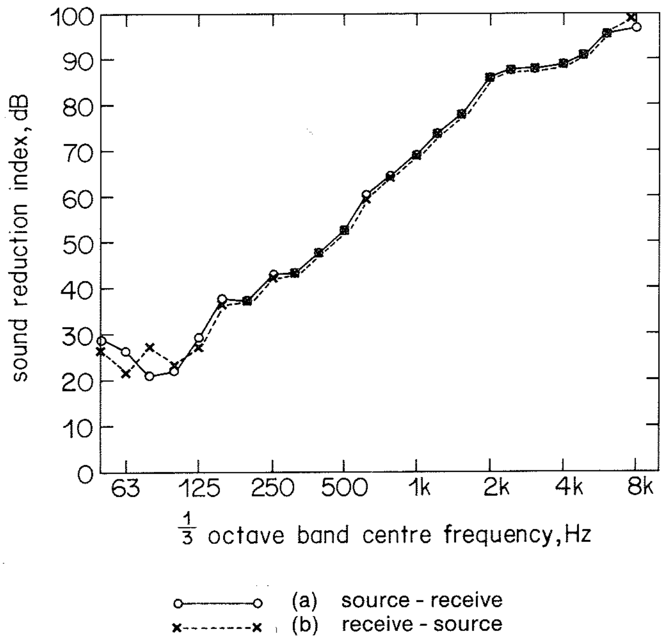

Fig. A1 - The effects of measurement direction on the SRI of a partition in the Transmission Suite.

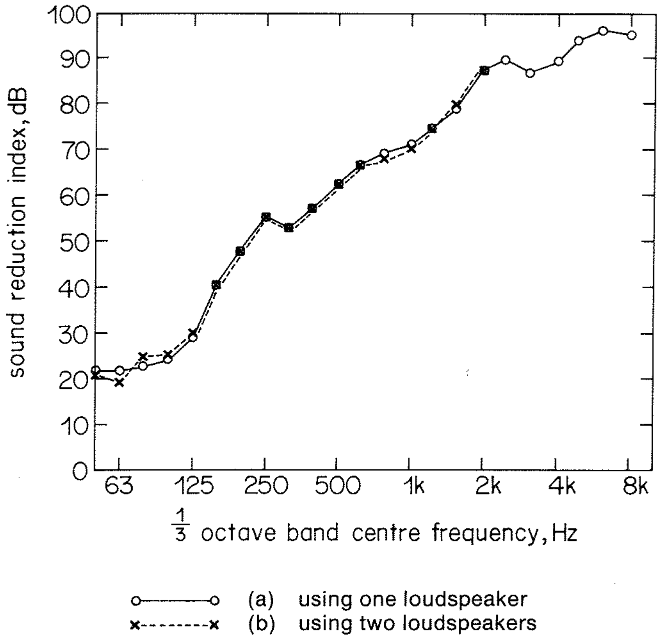

Fig. A2 - The effects of diffusion in the source room on the SRI of a partition.

Diffusers had been fitted in the receive room only, at the time when the work reported here was carried out. It could be argued, therefore, that the measured sound insulation of the test partition might be incorrect if the sound field in the source room was not sufficiently diffuse. To investigate whether this was true, the sound insulation was measured for a partition not described in this Report, using either one loudspeaker as the noise source in the source room, or two loudspeakers at different positions in the source room, driven by independent pink noise sources at the same level (this should give a more diffuse field than using only one loudspeaker). The results are shown in Fig. A2. The two insulation curves agree very closely, and the small differences between the curves can be explained in terms of the repeatability of measurements. Thus it can be said that the state of diffusion in the source room is probably sufficient, and that results will be reliable even at low frequencies.